Chapter 6

# Peripheral Tissue Oxygenation During Standard and Miniaturized Cardiopulmonary Bypass (Direct Oxymetric Tissue Perfusion Monitoring Study)

Jiri Mandak

Additional information is available at the end of the chapter

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## 1. Introduction

Coronary artery bypass grafting (CABG) using a cardiopulmonary bypass (CPB) is a routine therapeutic method in the surgical treatment of ischemic heart disease. Although CPB is successfully used thousands of times each day worldwide it is still associated with some unanswered questions [1].

One of the basic questions that arise with the use of this technology is an adequate blood flow during surgery [1,2]. There are no standards for optimal pump flow during CPB and institutional practices are largely based on empirical experience. Optimal blood flow rate has not been definitively established by large-scale randomized trials carried out on animal models more than fifty years ago and proved by clinical experiences [1,3]. Initial flow is calculated based upon the body surface area and a temperature management strategy. The flow rate most commonly used during hypothermic CPB is 2.2 - 2.4 l.min-1.m-2 and during normothermic CPB 2.5 - 2.8 l.min-1.m-2 [3].

Despite progress, cardiopulmonary bypass predominantly used during coronary operations is still associated with profound physiological reactions and changes. In the majority of cases these reactions are caused by contact of blood with artificial material within the system and by other sources such as coronary suction, blood-air contact, non-turbulent flow, hemodilution and hypothermia.

A large number of advancements in the technology, equipment and techniques have been introduced to decrease the negative impact of CPB. One of the latest complex innovations is miniaturized CPB (mini CPB). The use of more biocompatible materials and minimization of equipment and internal surface of the system can reduce pathological reactions [4-8].

Volume constant perfusion (perfusion without a reservoir) is a major advantage of mini CPB, but it can be associated with significant problems. The calculated blood flow (pump flow) must often be reduced to compensate for the volume in case of lower venous return during perfusion. Other reasons for reduction in pump flow are an increase in arterial pressure and flooding of the operating field with blood.

Delivery of oxygen to the tissues is equally dependent on blood flow and the O2 content of blood. Reduction of blood flow can decrease optimal tissue oxygenation. Inadequate oxygenation and perfusion can be associated with severe pathological peripheral tissue changes associated with clinical complications [1,9,10].

It is difficult to assess local changes in perfusion or blood circulation in the periphery. The direct measurement of blood flow through separate organs or skeletal muscles during cardiac surgery is both technically difficult and ethically unacceptable. Evaluation of the standard biochemical and hemodynamic parameters (blood pressure, blood lactate, heart rate, O2 saturation in the capillary bed, diuresis, etc.) yields for general results but not for regional changes [1,3,9].

For this purpose, direct continuous measurement of interstitial tissue oxygen tension (ptO2) of a skeletal muscle, as a typical peripheral tissue, was used in this study. Tissue oxygen tension reflects the adequacy of regional tissue oxygenation and perfusion [11,12].

Oxygen tension was measured with a special optical multiparametric sensor inserted into the patient´s deltoid muscle. The sensor is based upon the principle of fluorescence quenching whereby the intensity of a fluorescent optical emission form, an indicator, is quenched (reduced) in the presence of oxygen. Oxygen from the surrounding blood equilibrates with the sensor materials and quenches the fluorescent light. This method was introduced into brain and liver perfusion measurement but it has not been used in connection with cardiopulmonary bypass until now.

The present study was designed to evaluate changes in peripheral tissue (skeletal muscle) oxygenation during cardiac surgery and to compare tissue perfusion in relation to blood flow during standard CPB versus mini CPB.

## 2. Patients, materials and methods

The study was carried out at the Department of Cardiac Surgery, University Hospital and Faculty of Medicine in Hradec Kralove, Charles University in Prague, Czech Republic. The study was approved by the university Ethics Committee. Patients were given a prior detailed explanation of the study and signed an informed consent.

### 2.1. Patients

The sample included 40 patients with ischemic heart disease (32 men and 8 women). All patients underwent elective cardiac surgery. The exclusion criteria were concomitant surgery,

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an emergency procedure, patients with local, systemic infection or inflammation, severe left ventricular dysfunction (ejection fraction < 25%), renal failure (serum creatinine >180 μmol $l^{-1}$ or active renal replacement therapy).

The patients were randomized to two groups. Group A, consisting of 20 patients who underwent the conventional myocardial revascularization, coronary artery bypass grafting (CABG) using standard CPB and Group B, consisting of 20 patients who underwent coronary surgery using miniaturized CPB (Figure 1).

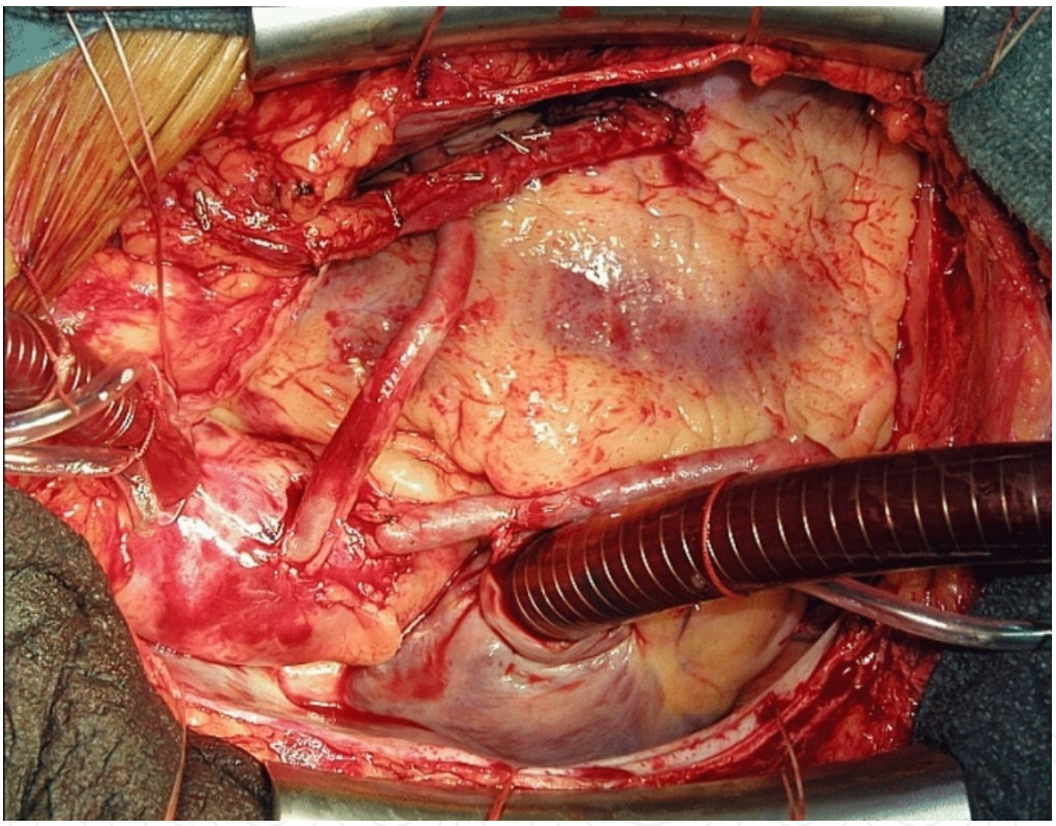

**Figure 1.** Coronary artery bypass grafting using cardiopulmonary bypass

Patient preoperative characteristics (Table 1), operative (Table 2) and postoperative data (Table 3) were prospectively recorded. The differences between groups (age, accompanying disease) were not statistically significant (Table 1). All routine therapeutic and monitoring steps commonly used with this diagnosis were performed. After clinical and angiographic evaluation the patients were randomly assigned to the study (n = 40).

| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **Male sex (%)** | 17 (85%) | 15 (75%) | n.s. |
| **Age (y)** | 69 ± 5.8 | 67 ± 6.8 | n.s. |
| **Body mass index(kg.m$^{-2}$)** | 29 ± 4.9 | 28 ± 4.3 | n.s. |
| **Ejection fraction(%)** | 57.8 ± 9.8 | 56.2 ±12.7 | n.s. |
| **Prior myocardial infarction** | 12 | 12 | n.s. |
| **Prior PCI** | 4 | 4 | n.s. |
| **Hypertension** | 18 | 18 | n.s. |
| **Diabetes mellitus** | 7 | 6 | n.s. |
| **Chronic obstructive airway disease** | 3 | 2 | n.s. |
| **Euroscore** | 5.2 ± 4.7 (1.4-15.1) | 4.6 ± 3.5 (0.9-15.6) | n.s. |

**Table 1.** Preoperative characteristics of Group A (standard CPB) and Group B (mini CPB)

| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **Operation time (min)** | 254 ± 21.7 | 247 ± 58.1 | n.s. |
| **CPB time (min)** | 87.4 ± 21.7 | 75.7 ± 20.9 | n.s. |
| **Aortic crossclamp (min)** | 48.9 ± 14.5 | 45.4 ± 14.8 | n.s. |
| **No. of distal anastomoses** | 2.9 ± 0.8 | 2.7 ± 0.7 | n.s. |
| **Flow calculated (l.min$^{-1}$)** | 4.7 ± 0.39 | 4.6 ± 0.45 | n.s. |
| **Flow real (l.min$^{-1}$)** | 4.9 ± 0.41 | 3.5 ± 0.51 | <0,001 |
| **Priming (ml)** | 1501 ± 44 | 837 ± 205 | <0,001 |
| **Mean hematocrit (%)** | 25.3 ± 1.1 | 31.0 ± 2.3 | <0,001 |
| **Lowest temperature (ºC)** | 35.5 ± 0.4 | 35.7 ± 0.7 | n.s. |

**Table 2.** Operative characteristics of Group A (standard CPB) and Group B (mini CPB)

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| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **IM** | 0 | 0 | n.s. |
| **Strokes** | 1 | 0 | n.s. |
| **Atrial fibrilation** | 6 | 2 | <0,001 |
| **30-d mortality** | 0 | 0 | n.s. |
| **Low cardiac output** | 2 | 1 | n.s. |
| **Renal failure** | 0 | 0 | n.s. |
| **Blood loss per 24 hours (ml)** | 685 ± 342 | 861 ± 552 | n.s.(0.57) |
| **Blood transfusion (units)** | 2.5 ± 1.4 | 2.7 ± 1.2 | n.s. |
| **ICU stay (hours)** | 70 ± 68 | 112 ± 225 | n.s. |
| **Hospital lenght of stay (d)** | 16.4 ± 6.8 | 16.2 ± 5.4 | n.s. |

**Table 3.** Postoperative characteristics of Group A (standard CPB) and Group B (mini CPB)

## 2.2. Anesthetic technique

The anesthetic managements, CPB and surgical procedures were standardized in both groups. Anesthesia was induced with intravenous thiopenthal or midazolam and sufentanyl with muscle relaxation using cisatracurium. Anesthesia was maintained by an infusion of cisatracurium, sufentanyl and propofol at doses sufficient to keep the patient adequately anesthetized and hemodynamically stable. Isoflurane was added in the inhaled air. Antibiotic prophylaxis was given in accordance with the standard protocol (Unasyn, Pfizer, Italy; 3x1.5 g). In all cases the surgical approach was through median sternotomy.

## 2.3. Technique of CPB

### *2.3.1. Standard CPB technique (Group A)*

Cardiopulmonary bypass was established by standard aortic cannulation and two-stage venous cannulation of the right atrium. Antegrade cold blood cardioplegia (blood and St. Thomas´ solution in a ratio of 4:1) and topical cooling for the arrested heart and myocardial protection were employed. Anticoagulation was induced before CBP with heparin (2.5 mg $^{+}$kg-1), and the activated clotting time (ACT over 480 seconds) was monitored. Heparin was neutralized with protamin in a 1:1 ratio.

The extracorporeal circuit consisted of a hollow fiber membrane oxygenator (PrimO2x, Sorin Group, Italy) and roller pump with a non-pulsatile flow (Stockert S3, Sorin Group, Germany) in an open modification with 40.0 μm arterial line filter (Dideco Micro 40R, Mirandola,

Italy). The oxygenator and tubing system were primed with a mixture of crystalloid (Hartmann´s solution), colloids (Voluven), 10% Mannitol solution, 8.4% sodium bicarbonate, magnesiumsulphur solution, 5.000 IU of heparin. The CPB involved normothermia and calculated blood flow 2.4 - 2.8 $l.m^{-2}$. Mean arterial pressure during CPB was maintained at 50 to 75 mmHg and hematocrit above 0.22%. The acid base status was maintained using the alpha-stat perfusion strategy (Figure 2).

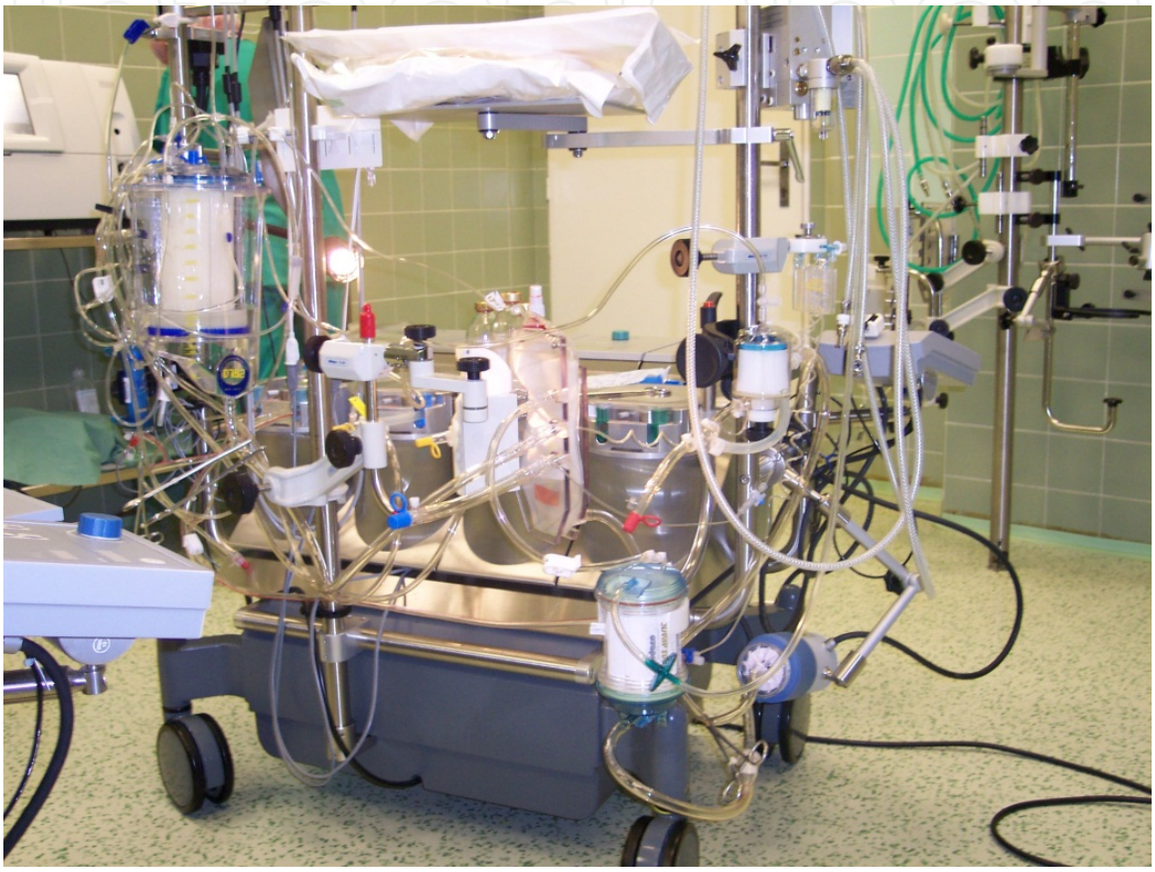

**Figure 2.** Standard cardiopulmonary bypass equipment

*2.3.2. Miniaturized CPB technique (Group B)*

Miniaturized CPB was established using aortic cannulation and a two-stage venous cannulation of the right atrium. A fully integrated minisystem (Synergy SorinR, Sorin Group, Italy) consisted of a centrifugal pump, membrane oxygenator, 40.0 μm arterial line filter and a venous bubbletrap. Cardiotomy suction and vents were not used. The whole system was a closed loop with the internal surface treated with a phosphorylcholin coat

(PH.I.S.I.O, Sorin Group, Italy) and very short tubing. The priming solution, heparinization, calculated blood flow, temperature and surgery technique were identical to the standard CPB (Group A). While initiating CPB, crystalloid priming was retrogradely flushed with blood from the arterial line to minimize hemodilution (retrograde autologus priming). Pro-

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tection of the myocardium during surgery (blood cardioplegia and topical cooling) was the same as in Group A (Figure 3, 4).


**Figure 3.** Miniaturized integrated CPB system (Synergy Sorin, Sorin Group, Italy)

### 2.4. Monitoring technique

Before the surgical procedure, at the time of anesthesia introduction, the optical multiparametric sensor (NeuroventR PTO, Raumedic AG, Germany) (Figure 5) was inserted under sterile conditions into the right deltoid muscle without the use of local anesthesia (Figure 6). Continuous measurement of interstitial tissue oxygen tension (ptO2) was made during the surgical procedure and postoperatively by a special monitoring system (DataloggerR MPR2 logO, Raumedic AG, Germany) (Figure 7,8).

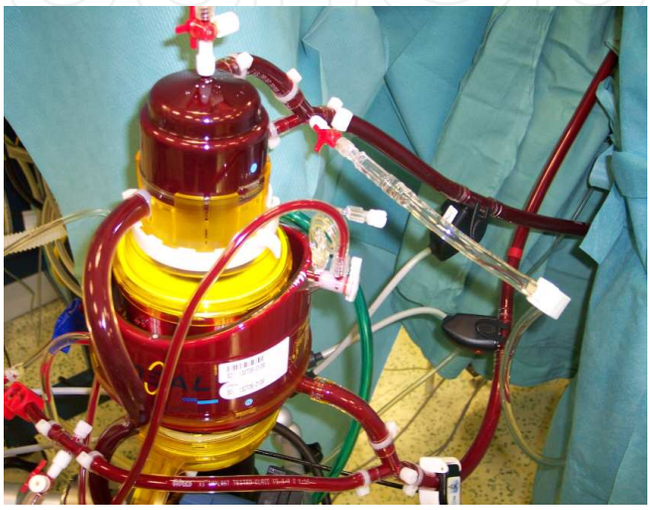

**Figure 4.** Miniaturized integrated CPB system (Synergy Sorin, Sorin Group, Italy) during surgery

**Figure 5.** Multiparametric sensor Neurovent® PTO (Raumedic AG, Germany)

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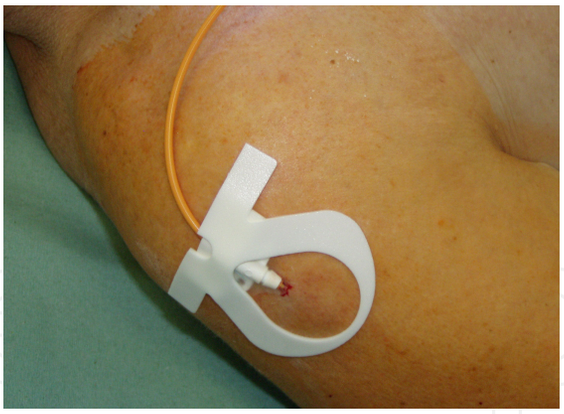

**Figure 6.** Sensor inserted into the right deltoid muscle

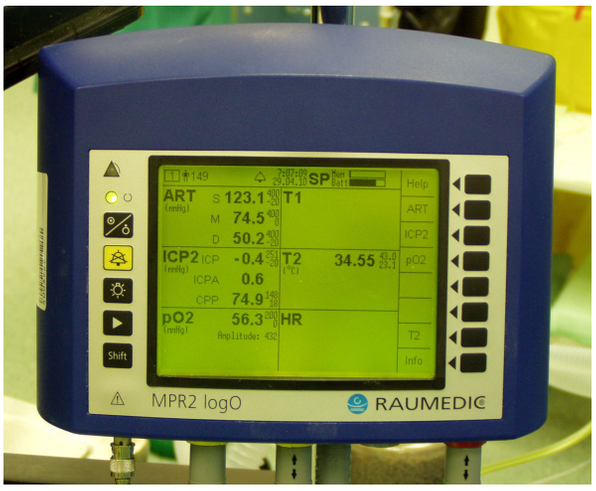


**Figure 7.** Analyzer Dattaloger® MPR2 logO (Raumedic AG, Germany)

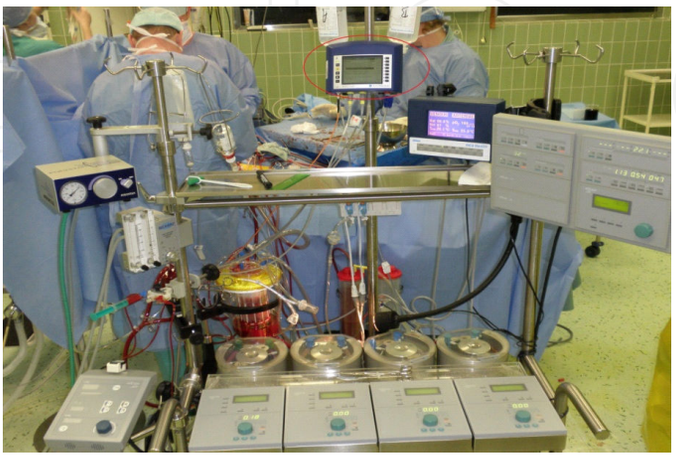

**Figure 8.** Analyzer Dattaloger® MPR2 logO (Raumedic AG, Germany) during CPB

Arterial blood pressure, blood flow during CPB, laboratory markers of tissue perfusion, blood gases and body temperature were recorded and analyzed as well.

Data from the oxymetric catheter in all patients were compared at the following time intervals: 1) 30 min after incision, 2) 15 min before CPB, 3) CPB, 4,5,6- at 20 min intervals during CPB, 7) end of crossclamp, 8) 15 min. after release of crossclamp, 9) end of CPB, 10) 15 min after termination of CPB, 11) end of surgery, 12,13,14- at 1 h intervals in the I.C.U.

### 2.5. Statistical analysis

Demographic and perioperative data are reported as number, means ± standard deviation (S.D.) or median. Comparisons between preoperative characteristics and perioperative data were made using the Student´s *t* test or the Mann-Whitney U-test and Kolmogorov-Smirnov test where appropriate. Values are expressed as means ± standard error of the mean (S.E.M.). Intergroup comparisons between two variables at the same time point were performed using the Mann-Whitney U-test. Group comparison was done using the Wilcoxon test for paired data.

The data were analyzed using the programs NCSS 2004 and Statistica. Differences were considered statistically significant at the level of $P<0.05$.

## 3. Results

40 patients (32 men, 8 women) were included in the study. The mean age ± S.D. was 69 ± 5.8 years in Group A and 67 ± 6.8 years in Group B. Preoperative patient characteristics are presented in Table 1. There were no statistical significant differences in preoperative characteristics between the groups.

Operative data are listed in Table 2. The groups were comparable for these parameters.

Statistically significant differences were found when groups were compared in regard to the use of a lesser priming volume in mini CPB as one of its main advantages in comparison with standard CPB (1501 ± 44 ml in Group A vs. 837 ± 205 ml in Group B). It was also associated with a lower drop in hematocrit level during CPB (25.3 ± 1.1% in Group A and 31.0 ± 2.3% in Group B). The immediate postoperative values of hematocrit (ICU admission) were not significantly different.

Analysis of the data during CPB showed differences betweens groups.

The main difference was a lower real blood flow during CPB in Group B (3.5 ± 0.51 $l.min^{-1}$) vs. calculated flow (4.6 ± 0.45 $l.min^{-1}$) than real flow in Group A (4.9 ± 0.41 $l.min^{-1}$) vs. calculated flow (4.7 ± 0.39 $l.min^{-1}$) (Table 2).

There was a direct correlation between mean arterial pressure (MAP) and ptO2 in Group A during CPB (↓MAP ≈ ↓ ptO2). Pumped blood flow was continuously maintained at the same calculated level. A decrease in ptO2 levels without correlation to MAP was found during surgery after CPB (Figure 9).

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On the other hand, a direct correlation between pumped blood flow and MAP (↓flow ≈↓MAP) was found during CPB in Group B. The value of ptO2 was continuously higher and independent at this time. A decrease in ptO2 levels without correlation to MAP was found during surgery after CPB as in Group A (Figure 10).

Lower levels of ptO2 without correlation to MAP were analysed postoperatively in both groups and we observed a trend towards a reduced ptO2 during the first hours after admission to the intensive care unit (Figure 9,10).

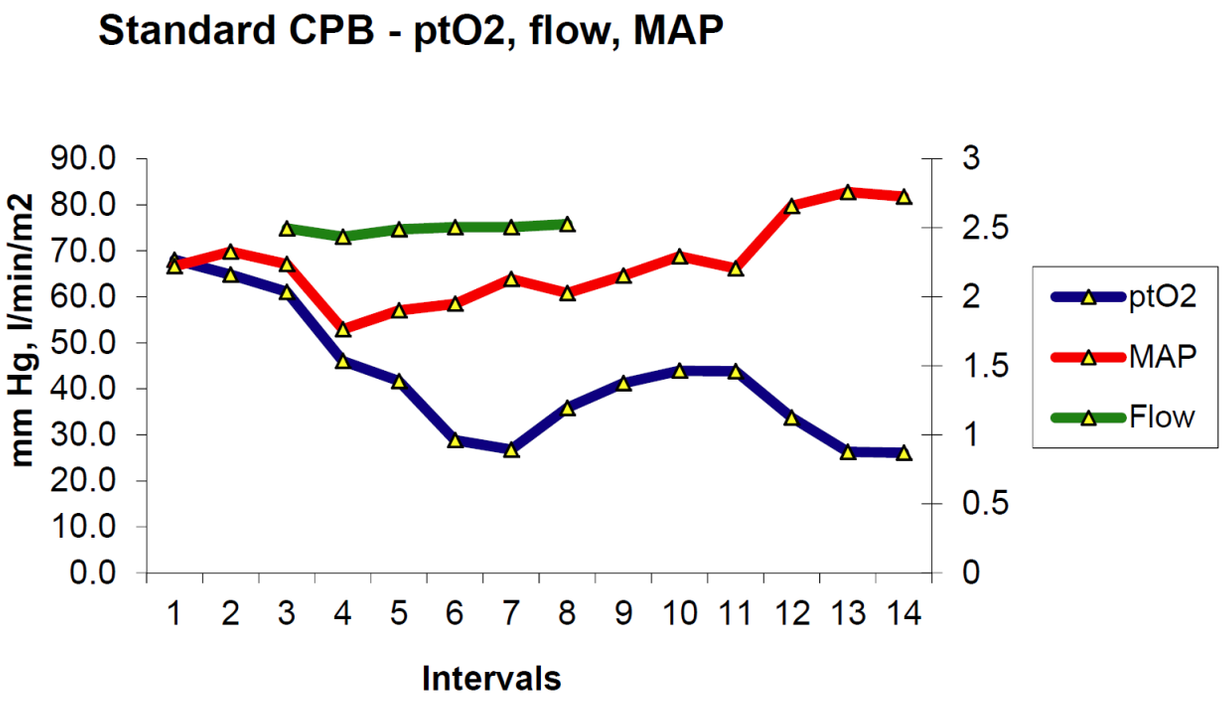


**Figure 9. Levels of $ptO_2$, blood flow and MAP in Group A (standard CPB) in intervals** (Intervals: 1- 30 min. after incision, 2- 15 min. before CPB, 3- CPB, 4,5,6- à 20 min. of CPB, 7- end of crossclamp, 8- after 15 min., 9- end of CPB, 10- after 15 min., 11- end of surgery, 12,13,14- à 1 h. I.C.U.)

Changes of ptO2 at this time compared with initial level are shown in Figure 11.

Higher levels of ptO2 during and after CPB in comparison with initial levels were observed in Group B. A decrease in ptO2 levels after surgery was found in both groups.

Changes in flow (%) in time compared to calculated flow are shown in Figure 12.

A higher blood flow during perfusion was analysed in Group A and lower than calculated blood flow was found in Group B.

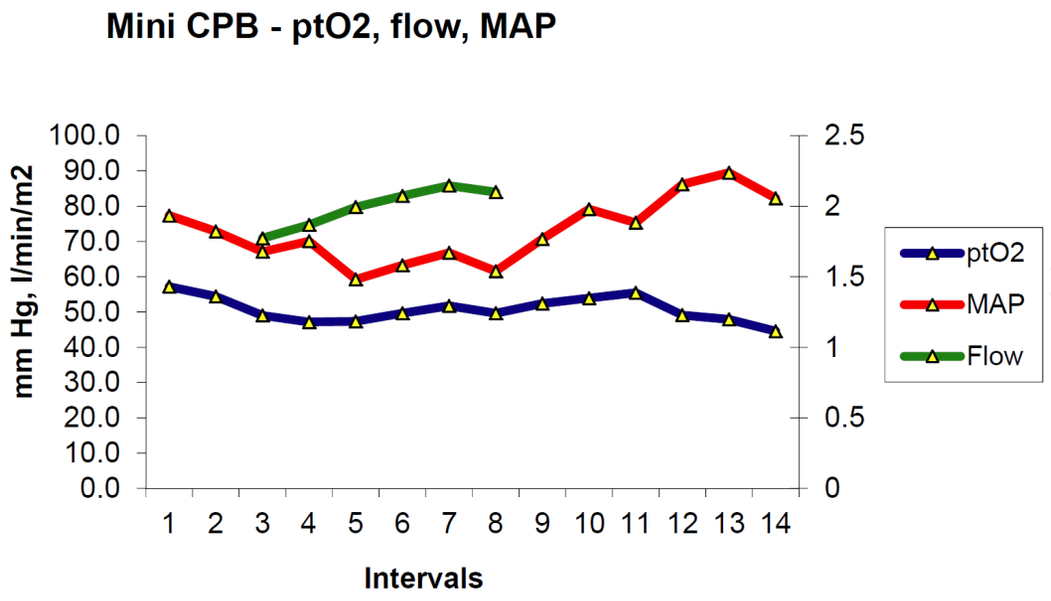


**Figure 10. Levels of $ptO_2$, blood flow and MAP in Group B (mini CPB) in intervals** (Intervals: 1- 30 min. after incision, 2- 15 min. before CPB, 3- CPB, 4,5,6- à 20 min. of CPB, 7- end of crossclamp, 8- after 15 min., 9- end of CPB, 10- after 15 min., 11- end of surgery, 12,13,14- à 1 h. I.C.U.)

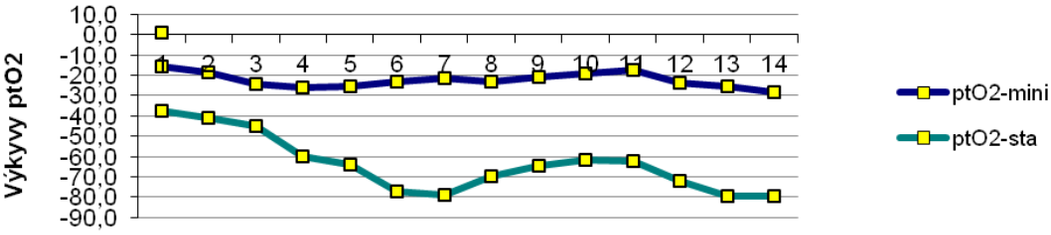


**Figure 11.** Changes of $ptO_2$ compared to initial levels (%)(Group A- green line, Group B- blue line. Intervals: 1- 30 min. after incision, 2- 15 min. before CPB, 3- CPB, 4,5,6- à 20 min. of CPB, 7- end of crossclamp, 8- after 15 min., 9- end of CPB, 10-after 15 min., 11- end of surgery, 12,13,14- à 1 h. I.C.U.)

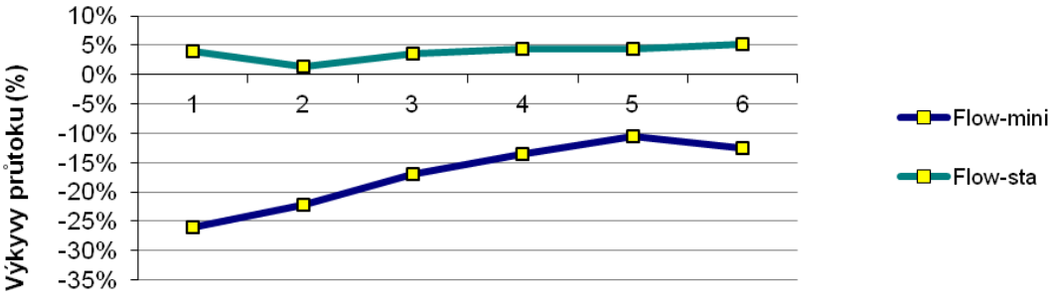


**Figure 12.** Changes in blood flow (%) during perfusion compared to calculated flow (Group A- green line, Group B- blue line. Intervals: 1- CPB, 2,3,4- à 20 min. of CPB, 5-end of crossclamp, 6- after 15 min.)

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We also observed a lower muscle oxygen (ptO2) tension than in arterial blood during the whole operation in both groups.

Peri-operative biochemical parameters of perfusion (arterial blood gas variables) are shown in Table 4. There were no statistically significant differences.

| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **pH** | | | |
| **before CPB** | 7.41 ± 0,06 | 7.42 ± 0,04 | n.s. |
| **during CPB** | 7.42 ± 0,07 | 7.41 ± 0,03 | n.s. |
| **after CPB** | 7.39 ± 0,03 | 7.37± 0,04 | n.s. |
| **$pO_2$ [mm Hg]** | | | |
| **before CPB** | 142 ± 81 | 182 ± 72 | n.s. |
| **during CPB** | 171± 31 | 191 ± 31 | n.s. |
| **after CPB** | 191 ± 71 | 189 ± 48 | n.s. |
| **$pCO_2$ [mm Hg]** | | | |
| **before CPB** | 35 ± 3 | 37 ± 4 | n.s. |
| **during CPB** | 38 ± 6 | 39 ± 3 | n.s. |
| **after CPB** | 39 ± 5 | 37 ± 7 | n.s. |
| **BE** | | | |
| **before CPB** | - 0.53 ± 1.72 | - 0.54 ± 1.34 | n.s. |
| **during CPB** | 0.45 ± 1.91 | 0.29 ± 1.72 | n.s. |
| **after CPB** | - 1.39 ± 1.8 | - 0.40 ± 1.4 | n.s. |
| **$DO_2$ [ml.min-1.m-2]** | 259 ± 34 | 256 ± 39 | n.s. |

**Table 4.** Laboratory characteristics of perfusion (arterial blood gases)

There were no significant differences in postoperative levels of lactate and arterial blood gas variables between groups (Table 5).

| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **pH** | | | |
| **I.C.U. admission** | 7,45 ± 0,03 | 7,46 ± 0,06 | n.s. |
| **I.C.U after 6 h** | 7,37 ± 0,05 | 7,43 ± 0,03 | n.s. |

| | Group A (n=20) | Group B (n=20) | p-value |
|---|---|---|---|
| **1. postoper. day** | 7,40 ± 0,07 | 7,39 ± 0,05 | n.s. |
| **$pO_2$ [mm Hg]** | | | |
| **I.C.U. admission** | 98 ± 48 | 97 ± 60 | n.s. |
| **I.C.U after 6 h** | 171 ± 25.9 | 170 ± 50 | n.s. |
| **1. postoper. day** | 135 ± 39 | 141 ± 28 | n.s. |
| **$pCO_2$ [mm Hg]** | | | |
| **I.C.U. admission** | 30 ± 5 | 32 ± 4 | n.s. |
| **I.C.U after 6 h** | 35 ± 4 | 39 ± 6 | n.s. |
| **1. postoper. day** | 36 ± 5 | 35 ± 4 | n.s. |
| **BE** | | | |
| **I.C.U. admission** | - 2.93 ± 2.34 | - 3.28 ± 2.31 | n.s. |
| **I.C.U after 6 h** | - 1.8 ± 1,71 | - 2.16 ± 2.0 | n.s. |
| **1. postoper. day** | - 2.61 ± 1.83 | - 3.15± 1.91 | n.s. |
| **Lactate [mmol/l]** | | | |
| **I.C.U. admission** | 1.9 ± 0.7 | 2.1 ± 1.3 | n.s. |
| **I.C.U after 6 h** | 1.8 ± 0.5 | 2.4 ± 1.7 | n.s. |
| **1. postoper. day** | 2.1± 0.9 | 2.3 ± 0.8 | n.s. |

**Table 5.** Postoperative laboratory characteristics of perfusion (arterial blood gases, lactate)

No death, acute renal failure, or stroke occured during the postoperative course either group. The only differences were postoperative atrial fibrillation (6 in Group A, 2 in Group B) (Table 3).

There were no cases of local complications at the site of inserted sensors, and there were no signs of general infection or sepsis in either group.

## 4. Discussion

The technology of miniinvasive systems has been in development since the beginning of the 1990s.

The benefits of using miniinvasive systems have been clearly proven in many publications. Studies show that the use of miniinvasive systems result in a decrease in quantity of administered blood derivatives, a decrease in blood loss, lower incidence of postoperative neurologic complications, a shorter stay in the ICU, period of artificial ventilation and total hospital stay [4-8].

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On the other hand some studies do not entirely confirm the positive clinical effect of using minisystems [13], even though the laboratory tests of these studies lean towards miniinvasive systems compared to standard CPB.

One discussed question while using CPB is the constant value of blood flow during the operation [1,2]. Preoperative calculated value of optimal blood flow using mini CPB is the same as standard CPB.

Nevertheless adequate and optimal blood flow during CPB is still an important question. There are no standards for optimal pump flow during CPB. Initial flow is calculated on the basis of body surface area and a temperature management strategy. The calculated blood flow often has to be decreased during perfusion using mini CPB.

The reason for the necessary decrease in pumped blood flow is the increase in arterial blood pressure during the operation most likely as a result of increased blood in the vascular bed (an absence of a CPB reservoir).

Another reason for decreased flow could be the flooding of the operating field during worsened venous return.

Decreased venous return could be another reason. The flow of a centrifugal pump during mini CPB is fully dependent upon adequate venous return with resultant filling of the venous bed of the patient.

In an effort to achieve the calculated blood flow the centrifugal rotational velocity is increased resulting in increased suction pressure within the venous part of the system and thus suction of the artifact with the venous cannulas. The ability to control flow via a cardiotomy reservoir is missed in this case. A possible solution is an increase of blood in the body (patient´s body position in space, application of vasopressors, filling of the circulatory system) or decreasing blood flow in the system. The "antitrendelenburg" position (head up), during which the filling of the lower half of the body is partly increased and consequently an increased venous flow (return), is of some advantage. Further, in this position the heart chambers are adequately emptied. The trendelenburg position described in the literature as a means to increase venous return has typically no effect when mini CPB is applied. In the case of a closed system the patient´s own body is the reservoir.

It is necessary during the procedure to have a coordinated approach between the surgeon, anesthesiologist and perfusionist.

During an acute case of a decrease in the pumped blood flow, in the presence of an impaired venous return, filling was supplemented by blood collected in a collapsible bag at the beginning of the operation. To restore satisfactory parameters usually a sufficient volume of less than 100ml was required.

The perfusion pressure in both groups was maintained at levels between 50-70 mmHg [1,3,9,10]. In the case of mini CPB this did not fall below 50 mmHg while on the other hand there was a tendency for higher levels of pressure.

Different results in comparison with both groups after analysis of ptO2, MAP and blood flow during CPB and postoperative course were found to our greatest surprise.

A direct correlation between mean arterial pressure (MAP) and ptO2 was observed in Group A during CPB. Pumped blood flow was continuously maintained at the same calculated level. On the other hand, direct correlation between pumped blood flow and MAP was found during mini CPB in Group B. The value of ptO2 was continuous, higher and independent at this time.

So far, we have no clear explanation for these differences in both groups. The main reason could most likely be due to differences in the amount of circulating blood volume, the possibility of using a cardiotomy reservoir, and the subsequent need to use catecholamines during perfusion.

A decrease in the ptO2 levels not correlated with MAP were analysed during CPB, after CPB and in the postoperative course in both groups. This is the most likely cause of decreased circulatory volume resulting in the use of vasopressors (catecholamines). A decrease in body temperature during this phase of the operation leading to peripheral vasoconstriction can also contribute equally to this phenomenon.

The lower level of acquired hemodilution (higher hematocrit) during the operation, determined by a lower filling volume and retrograde autologous priming are major advantages of using perfusion by mini CPB.

Supply of oxygen to the tissues during reduced flow of the bypass machine is therefore safe in the case of an increased hematocrit. In the mini CPB group, only 2/3 of the priming fluid was used as opposed to classical CPB and another 1/3 of this fluid was replaced by the patient's blood using retrograde autologous priming. The hematocrit provides sufficient capacity to supply oxygen in normothermia. A combination of decreased primary filling and a shortened tubing system resulted in an increased hematocrit and concentration of hemoglobin as expected in Group B (mini CPB).

In our study a closed integrated system coated with phosphorylcholine was used. The tubing system was shortened to a minimum, by placing it as close as possible to the patient, to minimalize priming. The system used allowed for partial back-flow of the patient´s own blood (retrograde autologous priming). Coronary suction was not used and neither was a venous reservoir. No cell saver device was used.

There were no technical perfusion linked complications.

In comparison to the perfusion parameters of both groups there were no differences during surgery. The monitored values of arterial blood gases were comparable and showed optimal perfusion management in both groups. Likewise, the values in both groups were comparable in the early postoperative course.

No death, acute renal failure, or stroke occurred in the postoperative course of either group. The only difference noted was in the incidence of postoperative atrial fibrillation with group B (mini CPB) showing better results. This study was limited by a small number of patients.

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In a comparison of monitored parameters of the clinical course we can suggest that lower values of blood flow during perfusion in group B (mini CPB) were sufficient and had no negative impact in the postoperative course.

Tolerance to decreased flow in mini CPB, with maintained sufficient blood pressure, is in our opinion due to a higher hematocrit. Decrease in volume of priming fluid together with technique of RAP ensures a decreased perioperative hemodilution and thus an increase in blood oxygen carrying capacity.

Another improtant postive aspect of using mini CPB is also a decrease in microcirculatory dysfunction. The system design (closed loop, biocompatible surface area, centrifugal pump, and elimination of cardiotomy suction) and decreased contact with artificial surfaces (shortened tubing system and absence of cardiotomy reservoir) during lower flow decreases the negative impact on the organism. A lower intensity in the inflammatory reaction results in a decreased dysfunction of the endothelium and subsequent malperfusion. To verify this impact of the minisystem on the microcirulation it is necessary to perform further studies.

## 5. Conclusion

A miniaturized system of CPB enables perfusion with relatively low flow and in normothermic conditions. Monitoring perfusion of skeletal muscle during the operation and our experience shows that it is a safe method of perfusion.

Our work experience and the results of this pilot study suggest that a flow decrease in mini CPB is well tolerated by the organism.

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## Author details

Jiri Mandak

Address all correspondence to: jiri.mandak@centrum.cz

Department of Cardiac Surgery, Charles University in Prague, Faculty of Medicine and University Hospital in Hradec Kralove, Hradec Kralove, Czech Republic

## References

[1] Murphy GS, Hessel EA, Groom RC. Optimal perfusion during cardiopulmonary bypass: An evidence-based approach. Anesth Analg 2009; 108:1394-417.

[2] Fernandes P, MacDonald J, Cleland A, Walsh G, Mayer R. What is optimal flow using a mini-bypass system? Perfusion 2010; 25:133-9.

[3] Lonsky V. Mimotelni obeh v klinicke praxi (Cardiopulmonary bypass in clinical practice). Praha: Grada Publishing, 2004. ISBN 80-247-0653-9.

[4] Koivisto SP, Wistbacka JO, Rimpilainen R, Nissinen J, Loponen P, Teittinen K, Biancari F. Miniaturized versus conventional cardiopulmonary bypass in high-risk patiens undergoing coronary bypass surgery. Perfusion 2010; 25:65-70.

[5] Curtis N, Vohra HA, Ohri SK. Mini extracorporeal culit cardiopulmonary bypass system: a review. Perfusion 2010; 25:115-24.

[6] Dobele T. Schwirtz G, Gahl B, Eckstein F. Mini ECC vs. Conventional ECC: an examination of velus oxygen saturation, hemoglobin, haematocrit, flow, cardiac index and oxygen delivery. Perfusion 2010; 25:125-31.

[7] Mazzei V, Nasso G, Salamone G, Castorino F, Tommasini A, Anselmi A. Prospective randomized comparison of coronary bypass grafting with minimal extracorporeal circulation system (MECC) versus off-pump coronary surgery. Circulation 2007; 116:1-7.

[8] Beghi C, Nicolini F, Agostinelli A, Borrello B, Budillon AM, Bacciottini F, Friggeri M, Costa A, Belli L, Battistelli L, Gherli T. Mini-Cardiopulmonary Bypass System: Results of a Prospective Randomized Study. Ann Thorac Surg 2006; 81:1396-1400.

[9] Boston US, Slater JM, Orszulak TA, Cook DJ. Hierarchy of regional oxygen delivery during cardiopulmonary bypass. Ann Thorac Surg 2001; 71:260-4.

[10] Haugen o, Farstad M, Kvalheim M, Rynning SE, Mongstad A., Husby P. Intraoperative fluid balance during cardiopulmonary bypass: effects of different mean arterial pressures. Perfusion 2007; 22:273-8.

[11] Benaron DA, Parachikov IH, Friedland S, Soetikno R, Brock-Utne J, van der Starre PJ, Nezhat C, Terris MK, Maxim PG, Carson JJ, Razavi MK, Gladstone HB. Continuous, noninvasive and localized microvascular tissue dimetry using virble light spectroscopy. Anesthesiology 2004; 100:1469-75.

[12] Soller BR, Idwasi PO, Balauger J, Levin S, Simsir SA, Vander Salm TJ, Collette H, Heard SO et al. Noninvasive, NIRS-measured muscle pH and PO2 indicate tissue perfusion for cardiac surgical patients on cardiopulmonary bypass. Crit Care Med 2003; 31:2324-31.

[13] Svitek V, Lonsky V, Mandak J, Krejsek J, Kolackova M, Brzek V, Kubicek J, Volt M. No clear clinical bendit of using mini-invasive extracorporeal circulation in coronary artery bypass rafting in low risk patiens. Perfusion 2009; 24:389-95.